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Research of Automotive Change Management and Combined Risk-Management Models

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Abstract

An Electronic-Control-Unit embedded within a car environment is constantly under attack of a continuous flow of modifications of specifications throughout the development life cycle until and beyond Start-of-Production. Root cause for modifications are for instance simply software or hardware errors, improvement for robust design or requirement changes to satisfy the forth-coming demands of the market to ensure later commercial success. Thus the pursuit for best in class products and self-preservation drives the need for modifications and effective methods to review all the side effects of changes before delivery. This paper focuses on the issue to tailor an automotive specific mechanism to guide the requirement change through all the stages determined by a typical automotive development until the settled feature meets the customer. The ability to control the requirement modification involves effective and reproducible procedures to deliver the so-called Request-for-Change (RfC, i.e. [1]) as specified. The Change-Management (CM) process should support all stakeholders with information such as the RfC transition status (i.e. reject, planned, implemented) and impact reports to the initial agreed objectives fixed by contract, which are product features, budget, schedule and quality. The research will not be limited, but focus the investigation of impacts of RfC during the early phase of the project, which are the Concept-Validation and Debugging-Phase. The second part of this paper will undertake the construction of risk management models, utilizing the RfC documentations and impact analysis information produced by the CM process. The research will lead to the understanding of the impact caused by a single RfC, and eventually summarizing the total risk faced by the project at any desired instance within the product life cycle. Finally the research will suggest a visualization model, which cultivates the data of continuous flow of requirement changes into early-warning system and fever curve of the project or a particular project milestone.

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Keywords: automotive engineering; change mangement, risk mangement, imapact analysis

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1. Introduction

Considering the development of an Electronic Control Units (ECU) in the specific area of automotive engineering and focusing for example on todays Electronic-Infotainment-System, which is divided into several Network-Community partners such as the Main Unit, the Display Unit, the Instrument Cluster Display and several comfort and driver assistance units, as shown in figure 1. Each ECU will be assigned and development by a specialized automotive supplier. It is common practice, not only in the automotive business to develop complex projects with partners "*to respond quickly to the changing need of customers*" (i.e. [7]) or market requirements and concentrate on the core business competency [7].

The objective of this paper is to examine the question how to handle requirement changes in general and taking into account the automotive environment, the development life cycle, the side effects of multi-partner-relationships, and most important to suggest such an automotive specific Change-Management (CM) process. This paper contributes to several papers and books [2-7] dealing already with CM processes, but commonly neglecting the consideration of the faced risk by approved or rejected requirement changes. Thus, the 2nd main focus is deliver a Risk-Assessment-Model embedded within such a CM construction, which is the key to meet the adjusted objectives to be ready as expected. The research will aim to drive a simple to use guided-tour to judge the risk, which is carried by each single change and as well as reviewing the total risk at a particular milestone.

This study will at first clarify the hard facts of an automotive project environment regarding project objectives, project phases, supplier (stakeholder) responsibilities and finally the sources of RfC's. The investigation will simulate along the stated framework (hard facts) the inflow flow of modifications of specifications throughout the development life cycle until SoP. The graphical visualization of the RfC inflow with respect to the development or project timeline will give a description of the critical issues the project is facing and possible remedies to sustain control of the project. The result of the analysis will provide supplementary tools for the state off the art CM Methods described in ITIL [2], [4] Software Engineering or [5] Requirements Engineering.

2. The need for Change Management and Risk-Management

2.1. Requirement Changes arise for a variety of reasons

Pro-actively:
- New requirements due to must have changes to satisfy the (strong) demand of market to ensure the later commercial success. *"Seeking business benefits such as reducing costs or improving services or increasing the ease and effectiveness of support"* [2] (page 54)
- Improvement for robust design. *"Be successful at the first attempt"* [2] (page 54)
- "*Make the changes as early as possible*", i.e. [12] and introduce changes before the Stabilization-Phase (fig.2)

Re-actively:
- Requirement changes due to insufficient or faulty function description of the specification (FRS)
- SW or HW implementation errors. *"Resolving errors and adapting to changing circumstances" [2] (page 54)*.
- Changes of network community partners (as shown in fig. 1) caused by various reasons as stated above.

2.2. The Environment of Research

Automotive developments are broken down into specialized project areas. Considering for example todays Electronic-Infotainment-Systems (see fig. 1), which are divided into several Network-Community partners (see figure 1). Each ECU will be assigned and development by a specialized suppliers (e.g. [7], section "*Requirements for collaborative, multi-company ECM*"). The research assumes that that all partner have proven their potential to meet the project objectives which is part of an initial project launch supplier assessment, proving their "*domain knowledge in your own field*" [11].

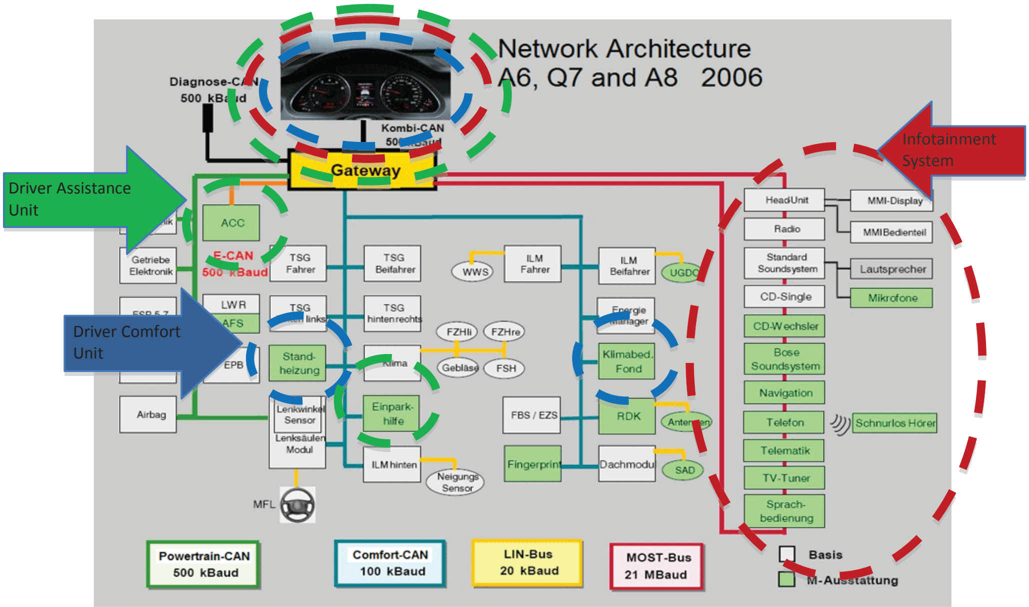

Fig. 1. ECU Network Community [8]

Nomenclature: Figure 1

Driver Assistance: e.g. ACC (Automatic Cruise Control), Parking Guidance (e.g. Einparkhilfe); **Driver Comfort Unit**: e.g. auxiliary heating (e.g. Standheizung); **Infotainment System:** e.g. Head-Unit (incl. the functions Radio, navigation, CD-drive, telephone, speech-control; **CAN, MOST:** Communication system to transport information between the Network partners; **Gateway:** Routes data, i.e. from Comfort-CAN-Bus to the Infotainment-MOST-Bus.

3. Project life cycle of Automotive Projects [9].

The titles and descriptions of the milestones vary with the OEM, understanding the story and the to-do’s behind the project landmarks is of utmost significant to appreciate the variations of possible impacts of RfC’s and their dependencies, i.e. at which release timing of the modification appears in the project schedule. As shown in figure 2 the development life cycle of automotive projects can be divided into three main parts such:

Concept-Development: The start of the CD phase is marked with the Project-Mission (PM) milestone and ends with the Concept-Development-Sample (CD-S). The goal of this phase is to develop upon a Requirements-Brief, stating for example the market positioning, technology and finances the Concept-Requirement-Specification (CRS). The final review of the Concept-Requirement-Specification will be based firstly upon a feasibility study (PF) and finally lead to a CD-D which could be a first HW/SW sample or just a computer simulation.

Concept Validation (CV): The CV lies in between the CD-Sample and the FRS-Sample, or more precisely the concept sample will reach within this period 100 % functionally. The FRS is the baseline for the nomination of the supplier. All contractual agreements such as functional content, schedule, finances and quality targets and so on are fixed within this document. The FRS is the INPUT of the supplier mission and the FRS-Sample the OUTPUT. The game for pushing the ECU functional quality to customer (SoP) maturity starts with the delivery of the FRS-Sample. The CV phase has two noticeable deliveries, the PoC-S and FRS-S.

Preparation of Production: This phase is marked by the OEM acceptance of the delivered FRS-S, which must also contain the documented proof of ECU status, such as test reports. The initial aim of this period is to locate all HW, SW and system problems and meet finally FRS defined quality targets. Thus, found problems require to be solved until the 0-Bug-Sample.

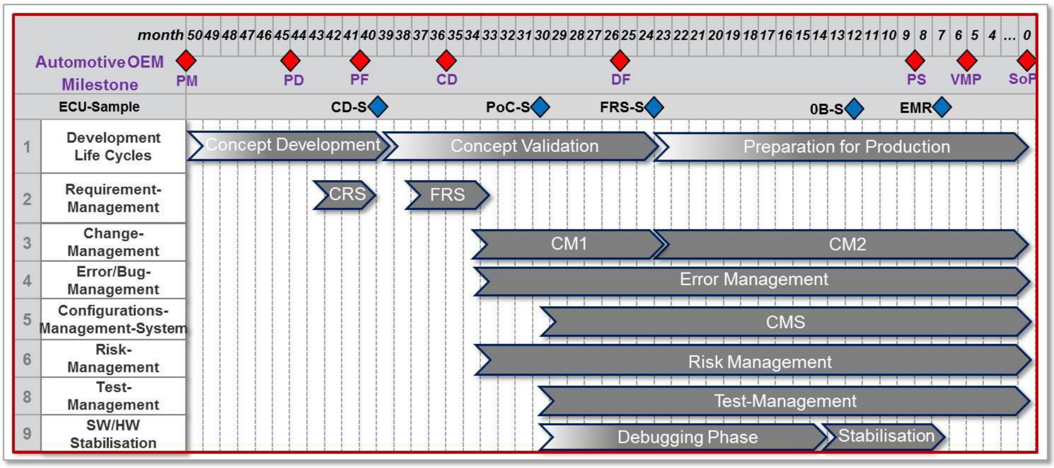

Fig. 2. Automotive Project Milestone-Plan with Process-Introduction and Deliverables [9].

Nomenclature: Figure 2 (i.e. [9])

General:
OEM: Original Equipment Manufacturer; **ECU:** Electronic Control Unit; **CMS:** Configuration Management System, i.e. [1]; **CM:** Change Management - *The process responsible for controlling the lifecycle of all changes,* i.e. [1]; **CRS:** Concept Requirement-Specification; **FRS:** The Final-Requirement-Specification is the INPUT of the contract given to several prospective suppliers for quotation and the 0-Bug-Sample the OUTPUT.
OEM Milestones:
(PM) Product-Mission; (PD) Product-Definition; (PF) Project-Feasibility; (CD) Concept-Decision; (DF) Concept Freeze; (PS) Pilot Series; (VMP) Validate production process for Mass Production; (SoP) Start of Production
ECU SW/HW Sample:
CD-S: Concept-Development-Sample; **PoC-S:** Proof-of-Concept Sample with respect to the FRS. The design task of the supplier is to integrate key parts to prove the general function. The sample is not intended to delivery error free functions it offers only a low level of maturity. **FRS-S:** 100% functionality according to the FRS, which means that all functions can be fully demonstrated within the car environment, but not necessarily error free. **0B-S**: 0-Bug-Samples are created on production tooling. All specifications for function, reliability, noise immunity, installation conditions, space requirement and the contacting correspond to final production status. The reproducibility in mass production must be ensured. **EMR:** The samples are manufactured with serial tools under production conditions.

4. Tailored Change Management (CM) process for Automotive Projects.

The following definitions and responsibilities have to be clarified to setup an automotive specific CM process shown in figure 3. The outlined process does not show all required 'RfC-questionnaire' formal or technical reviews for the sake of simplicity. However, the essential task of the shown CM process is to establish and sustain a relationship with the stakeholders, to support all with up-to-date information such as the RfC transition status (i.e. reject, planned, implemented) and impacts to the initial agreed objectives, which are features, budget, schedule and quality.

4.1. Start of the Change-Management (CM) and Risk-Management process

The CM will start at CM1 (see figure 2) and the Configuration Management System (CMS, i.e. [1]) will run simultaneously with the CM to record all RfC data. For risk management this investigation suggests that any deviation to the FRS; an RfC must be launched and run via a CM process. The benefit to start at CM1 phase is simply that all discussion and other findings are recorded into the FRS and not into emails or scratch pads to be eventually lost. Secondly and may be more important is that the consequence of neglecting to finalize the required change on contractual basis is the commercial impact review or influence is neglected. The presented CM Work Flow (figure 3) follows the concept of combining the requirement changes and bug reports within the same procedure.

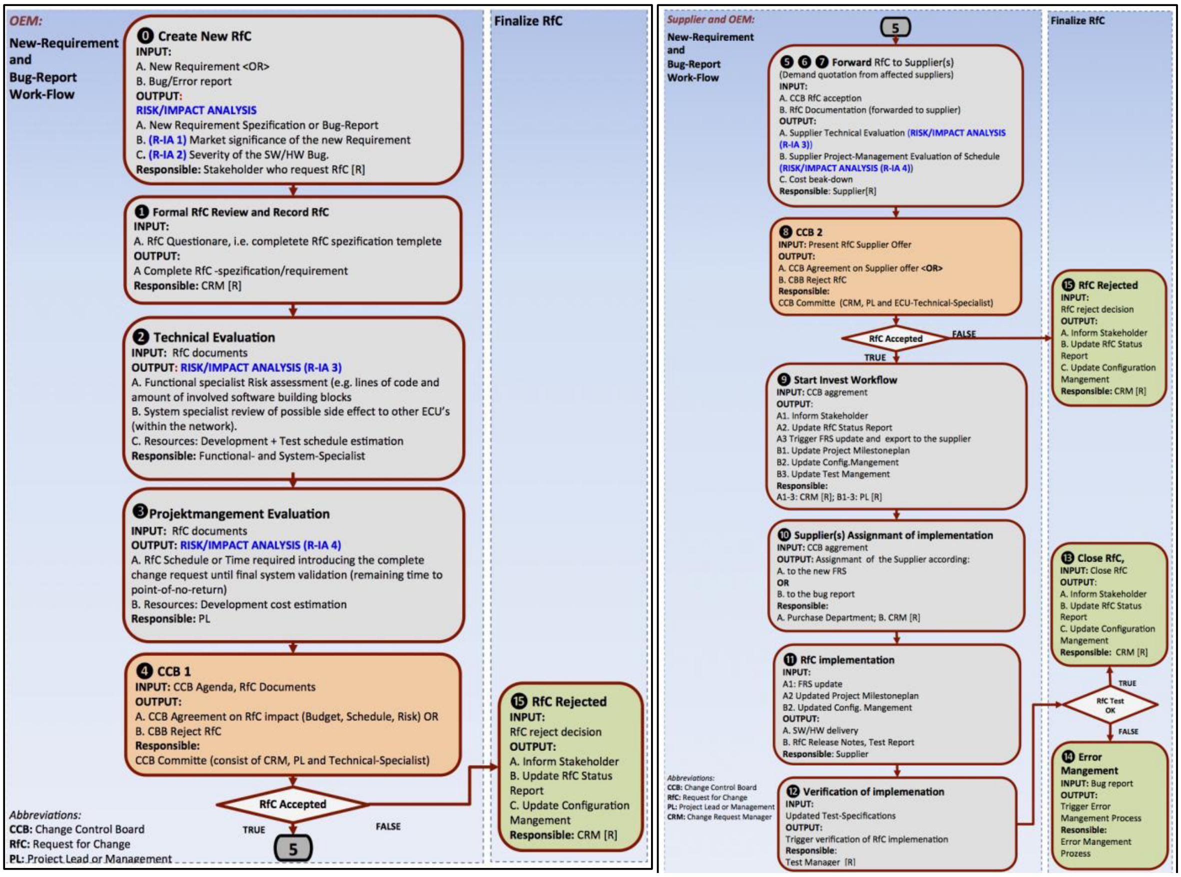

Fig. 3a and 3b Automotive Change Management (CM) Work Flow.

Nomenclature: Figure 3a/3b

RfC-in (see ❷): A new RfC base on bug-report or the new-requirement; **RfC-out** (see ⓭): A RfC is closed if the change is delivered, implemented and in car successfully tested; **RfC-Rejected** (see ⓯): Rejected CR's will be added to the RfC-out count; **RfC-active/open (❷-⓬):** The number of RfC-active/open corresponds with all RfC (RfC-in – RfC-out), which are still active; **RfC Questionnaire:** "The change record holds the full history of the change, incorporating information from the RfC and subsequently recording agreed parameters such as priority and authorization, implementation and review information." i.e. [6]

5. Practical Implementation the of CM Process in combination with Risk-Management Assessment

5.1. Practical analysis: Total of valid RfC in-flow w.r.t. the schedule (time)

Utilizing the explained ECU milestones (FRS-S, PoC-S, FRS-S, 0B-S and EMR) and the RfC-in and consequently the RfC-out flow the graphs shown in figure 4 can be drawn along the milestone FRS to EMR or SoP. The trend of simulated RfC-in and RfC-out flow corresponds to lessons-learned of previous projects [9]. The visualization of the in-flow and out-flow of RfC w.r.t. time shown in figure-4 is already common practice. From the shape of the simulated RfC in-/out-flow graph shown in figure 4 (RfC-in/-out/-active) can be deduced: The amount of active RfC shows the maturity of the ECU. Bearing in mind the agreed expectations of the ECU quality is defined and scheduled by the key milestones. The FRS-S milestone marks the 100% feature complete ECU maturity expectation. Moving towards the 0B-S milestone (0-bug Sample) the RfC inflow should decrease as a statement of functional stability. The described procedure only cultivates the RfC active curve into a fever (quality) chart of the project or a particular milestone. The graphs give no risk assessment support.

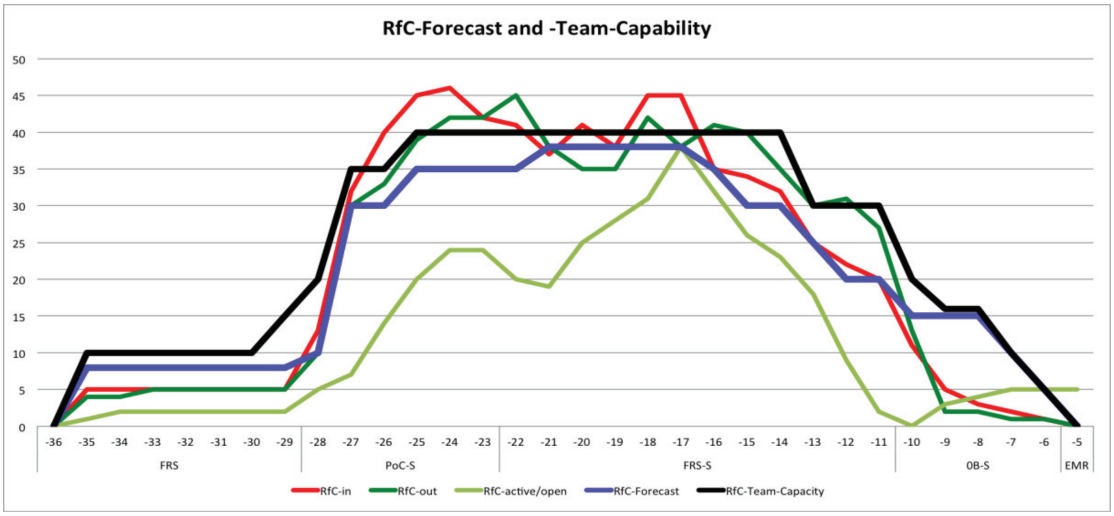

Fig. 4. RfC-in/-out/-active [9], Fig. 5. RfC-Forcast Model [9].

Nomenclature of Fig. 4 and Fig. 5

RfC: Request for Change. i.e. [1]; **RfC-in:** Total inflow of new RfC; **RfC-out:** Total if implemented or rejected RfC's. In short, closed RfC. **RfC-active/open:** Total amount of RfC-in - RfC-out.

5.2. Risk-Management Assessment via RfC-Forecast Model

It is common practise at the beginning of a project to describe within the Project-Brief the required Project-Infrastructure, see [13] *"Infrastructure Management Process" page 26*. The Project-Brief describes the demanded "*resources for the achievement of project objectives", [13] page 28*. In order to estimate the required project infrastructure such as human resources or budget, similar projects can be used as a baseline and compared to be project at hand. Thus, data or the amount of requirement changes and bug report experienced in on-going or closed project can be use to derive a graph to be used as a Forecast or expected RfC inflow. In fact this data can be used to establish and reason the Project-Briefs statement of required resources. Figure 5 shows such estimated RfC-Forecast graph. Reviewing the RfC-Forecast and the RfC-in graph with respect to the given milestone plan the following observations could be made, bearing in mind the maturity expectations of the ECU key milestones. If the inflow excites the forecast, countermeasures might to be necessary to return to the planned inflow (forecast). The technical staff and project management team defines the countermeasures after reviewing the RfC tickets. Possible results are: The assumption of (human) resources stated in the project brief, such as the RfC analysis and developer team were unrealistic to handle the project, and therefore the RfC-Forecast and the project infrastructure must be adjusted.

5.3. Risk-Management Assessment via RfC-Team-Capacity Model

The shape of the simulated RfC in-/out-flow graph shown in figure 4 (RfC-in/-out/-active) can be observed reviewing the data of several representative automotive projects, as stated in the previous chapter. Utilizing the data of such projects it is possible to construct the forecast model, most likely RfC inflow. Ideally the shape of the forecast curve must not be adjusted over the life cycle of the project, which is also a weakness of the Forecast-Model. The Forecast-Model take not into account the typical alterations of e.g. human resources and skills available. In order to improve the forecast model a “Human Resource” graph could be added to show the maximum team capacity to deal with the project requirements, i.e. [13] “Human Resource Management Process” page 29.

Plainly the graph must show the maximum human resources and skills available over time. Thus, the resulting team capacity must be able to produce the required RfC outflow to meet the project milestones. Introducing the described risk management control mechanism into figure 4 will conclude to figure 5 (RfC Forecast and Team Capacity). The data for forecast curve is idealized and leads to the shown curve. The data for the Team Capacity were derived as follows: During the early and the final phase of the project the Team-Capacity was set to equal or slightly larger values as the RfC-Forecast. During project phases were the probability growths that the RfC-inflow increases as described in chapter ‘Timeline and Constraints of valid RfC inflow’ the value of the Team-Capacity was set to at least 10% higher than the value given by the forecast as a save guard. The resulting data should be reused in the project brief, which *“assures the providing of a supply of skilled and experienced personnel qualified to perform life cycle processes to achieve organization, project and customer objectives.”* i.e. [13] page 29.

5.4. Risk-Management or Control of RfC inflow via Priority and Impact-Analysis Model

The Team-Capacity-Model curve states the maximum inflow of new RfC’s, which the total available project members at a specific time can handle. All previous discussed simulations only view the amount of new change requests, but not the impact of the bug or new requirement regarding (table 1: IA Focus):

- Market significance or consequences of introducing the feature at a later release.
- Severity of the SW/HW Bug to the customer or vehicle.
- Functional specialist risk assessment (e.g. lines of code, amount of involved software building blocks)
- Project-Management Evaluation of Schedule impact, such as time required introducing the complete change request until final system validation. Remaining time to until SW Freeze or SW stabilization.
- It is important to investigate the impact of an RfC to possible involved Network-Partners (see fig.1), i.e. [7].
- Implementation cost.

The question is therefore how to improve the discussed models to take the above stated possible arguments in to account, adding the impact of each argument to each single RfC. This Impact-Analysis (IA) is identifying or estimating the potential consequences and modifications to realize the change request. Table 1 shows an example of Impact-Analysis (IA) items (R-IA_1 to R-IA_5) and the corresponding assessments focus for each impact analysis item; whereas each items links to a rating or score (IA Score).

R-IA_1 and R-IA_2 gives the project management team a risk evaluation if the RfC **<u>is not implemented</u>**, with respect to market issues and to customer complaints. If the IA results into the highest impact sore, there is are very limited choices of not implementing the RfC as reasoned and shown in table 1. The Change Management (CM) Work Flow (see Fig. 3a.) suggests how to systemize or schedule the impact analysis R-IA_1 and R-IA_2. Responsible for the scoring is the stakeholder who initiates the RfC.
R-IA_3 and R-IA_4 gives the project management a risk evaluation if the RfC **<u>is implemented</u>**, with respect to engineering or SW/HW implementation effort, including involving of network partner. The CM Work Flow (see Fig. 3a.) suggests how to systemize or schedule the impact analysis R-IA_3 and R-IA_4. Responsible for the scoring

is the technical group that evaluates the RfC from the OEM point of view (see workflow process step ❷ and ❸). The scoring is might be adjusted after the suppliers review of the RfC via the supplier technical specialist (see fig 3b, CM process step ❺)

R-IA_5 states the implementation cost. Budget management will not to be considered within this impact analysis, but it is of vital importance that a new requirement is only realized after commercial agreement; otherwise the implementation work might be stopped or even dismantled. Loss of budget and resources are the consequence.

Risk(R)	**IA Focus**	**IA Priority: Assessments Description**	**IA Score**
R-IA_1	Market significance of the new Requirement	1. Immediate: *Meets legislative requirements"*, i.e. [2] page 55. 2. High: "*Responds to short term market opportunities or public requirements; Supports new business initiatives that will increase company market position"*, i.e. [2] page 55. 3. Medium: "*Maintains business viability; Supports planned business initiatives"*, i.e. [2] page 55. 4. Low: "*Improvements in usability of a service"*, i.e. [2]	1. IA: 4 2. IA: 3 3. IA: 2 4. IA: 1
R-IA_2	Severity of the SW/HW Bug (to the customer or vehicle)	1. Immediate: Car Immobility expected (i.e. low battery), "*Putting life at risk",* [2] page 55. 2. High: Customer complaint to be expected; "*Severely affecting some key users, or impacting on a large number of users"*, i.e. [2] p. 55. 3. Medium: "S*everely affecting some key users, or impacting on a large number of users"*, i.e. [2] page 55. 4. Low: "*No severe impact, but rectification cannot be deferred until the next scheduled release or upgrade"*, i.e. [2]	1. IA: 4 2. IA: 3 3. IA: 2 4. IA: 1
R-IA_3	Technical Evaluation	1. Immediate: High and Network-Partner are involved 2. High: High SW/HW implementation risk, without Network-Partners involvement or else jump to the next risk level. 3. Medium: Medium SW/HW implementation risk, without Network-Partners involvement or else jump to the next risk level. 4. Low: Low SW/HW implementation risk, without Network-Partners involvement or else jump to the next risk level.	1. IA: 4 2. IA: 3 3. IA: 2 4. IA: 1
R-IA_4	Project-Management Evaluation of Schedule impact*	1. Immediate: RfC implementation during and after the stabilization phase. 2. High: RfC implementation during the Preparation of Production phase, but before the SW/HW stabilization phase. 3. Medium: RfC implementation during the Concept Validation-Development phase 4. Low: RfC implementation during the Concept-Development phase *RfC SW/HW realization, test and final system implementation.	1. IA: 4 2. IA: 3 3. IA: 2 4. IA: 1
R-I_5	Implementation cost	Budget management will not to be considered within this impact analysis, but it is of vital importance that a new requirement is only realized after commercial agreement; otherwise implementation work might be stopped or even dismantled. Loss of budget and resources are the consequence.	-

Table 1. Impact-Analysis (IA) Items and Assessments.

The CM Workflow represents a systematic approach to control the inflow and analysis of RfC's to be implemented and presents the introduction of a CCB. The CCB decides whether a change will be rejected, integrated or postponed to a later release or even to a Model-Update (next generation) upon the result of the change request Impact-Analysis (IA) derived by different stages of the CM Workflow.

5.5. Combination of RfC-Team-Capacity Model and Impact-Analysis Model

RfC priorities (i.e. [2] page 55) as explained for R-IA_1 and R-IA_2 is partially known in the IT area. The impact priorities listed for R-IA_2 are commonly known (practise) in the automotive environment. R-IA_1 and R-IA_2 stating the severity of the problem to be solved if no solutions is found or implemented. Figure 6 shows for each new RfC the impact evaluation result according to table 1, utilizing the R-IA_3 and R-IA_4 priorities. R-IA_3 and R-IA_4 are considering the impact from the SW/HW/System-implementation threats and schedule perspective inflicted to the team.

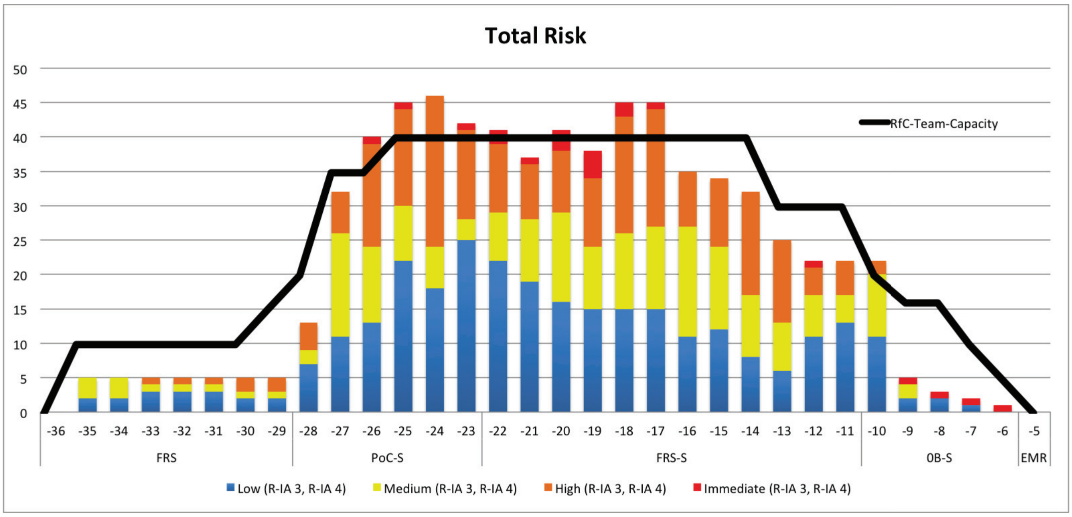

Fig. 6. Total (Implementation) Risk-Analysis and Team-Capacity.

6. Conclusions

6.1. Automotive Life Cycle

Understanding the automotive development life cycle is of paramount importance, before starting to construct any suitable tailored service process, which will be understood and accepted by the stakeholders. Effective process establishment *"does not happen until an organization recognizes the need for it and the benefits it will bring them", i.e.* [2]. From lessons learned, exploring any established institution or organization requires a thorough understanding of the actually applied and time-honored processes. The research of this paper is focused on the development of ECU's. Therefore the discussion suggests that the 'CM' in automotive ECU development projects starts directly after the freeze of FRS, which is the basis of the contract between OEM and supplier. If the research aims for the complete car development process the CM process start would probably be located at the Concept Requirement-Specification freeze. However, no harm done if the CM process start to early! The real benefit of the process is to collect the data describing the RfC and guide them through all the CM steps necessary to prepare the information required to take the adequate decisions with the best possible confidence and benefit for the business.

6.2. Change Management (CM)

The CM process secures the effective handling of RfC's from the initial need to change an existing or adopt a requirement until the delivery and test of the adopted functionality. Summarizing the services of the described CM workflow as shown in figure 3a/3b will lead to the following conclusion: The CM Process is a service, which collects all the predefined information at defined transition steps, triggers supportive processes such as requirement-, configuration-, risk-management (impact analysis) and CCB. The project team should define the RfC data required and collected by the CM service. Involving the team in defining the CM process will serve to define the best practice relegated RfC questionnaire and getting familiar with the goals and purpose of the service.

6.3. Risk Management (RM)

The Risk-Management Models discussed depending completely on the quality of information gathered by the CM service. The Forecast- and Team-Capacity processes depending also on the data gathered of previous projects and on the team member transferring the data to the new project (-brief). The Impact-Analysis Model depends especially on the engineering expertise of the stakeholders judging and deciding on the IA score. Clearly, this is the weakness of all risk models discussed, for example the impact score decision might not be reproducible for any specific RfC. The suggested remedy for the IA scoring of 'R-IA_3 Technical Evaluation' and 'R-IA_4 Evaluation of Schedule impact' is the review of the scoring (see fig. 3b). However, the marking of 'R-IA_1 - Market significance' and 'R-IA_2 - Severity of the Bug' are depending on personal experience and possibly fondness on a use-case or customer feature. However the Risk-Management Models are still valid tools for the project-lead and especially for the CCB to judge and to decide to implement or reject the RfC. The Team-Capacity Model is particularly important at the end of the project timeline, since misjudgement of RfC inflow rates are more difficult to compensate.

The Capacity-Model supports in addition the Human-Resource-Management to be considered for the project. It can be observed that companies plan to reduce the human resources, especially the experts required for bug tickets analysis at the end of the debugging phase. The graph of figure 5/6 could help at this point to argue against reduction of resources if the high amount of new RfC requires the opposite. At the very beginning of the project the is crucial to implement the Supplier-Management, i.e. [11] within the contract between the supplier and OEM, stating which project management tools and in the case of this paper the CM process landscape to be used. A Summary of the benefit of assigned priorities to each RfC are as follows:

- The project team can operate the implementation and test order in accordance to the priorities, i.e. 1st the RfC with highest IA score.
- For the configuration management the top score (immediate) RfC can influence the decision to release or postpone a SW/HW until this particular problem is solved, depending as well on the issue. However, the pre-marked top problem is marked to be especially treated with to priority and easily traceable.
- From the shape of the simulated Team-Capacity graph shown in figure 6 (RfC-in/-out/-active) in combination with the total impact analysis can be observed that if the maximum calculated impact comes near by or even crosses the Team-Capacity border appropriate management activities neat to be in place. "Resources utilization against capacity" (i.e. [2] page 18) needs to be considered. Figure 6 shows that for month '-26' until '-17' the resources will be sufficient to release all RfC's. Consequently, several obvious management decisions are possible: The RfC' marked with the Low priority need to be postponed or re-evaluated to reject candidates, or the team capacity needs to be upgraded until the month '17' (see figure 6).

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